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Woods Hole Oceanographic Institution

Cruise Report – Oceanus 218

March 20 – April 9, 1990

Warm Ring Inertial Critical Layer Experiment (WRINCLE)

by

Raymond W. Schmitt and Ellyn T. Montgomery

November 1991

Technical Report

Funding was provided by the National Science Foundation through Grant No.OCE 89-11053.

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Approved for Distribution:

James Luyten, Chairman
Department of Physical Oceanography

Table of Contents

List of Figures

List of Tables

Abstract

R/V Oceanus Cruise 218 (OC218) departed Woods Hole March 20, 1990 for 20 days of work in a Gulf Stream Warm Core Ring. The scientific objective of the Warm Ring Inertial Critical Layer Experiment (WRINCLE) was to study the phenomenon of inertial-internal wave trapping in anticyclonic rings and the associated mixing. High Resolution Profiler (HRP) casts provided fine- and microstructure data, and the Richardson Number float and eXpendable Current Profiler (XCP) surveys provided velocity and density finestructure measurements.

During the time R/V Oceanus was in and around the ring, 78 HRP drops to 1000 m were completed, and data from 55 XCPs, 26 Conductivity Temperature and Depth Profiler (CTD) casts, and 59 eXpendable BathyThermograph (XBTs) were logged. The free-drifting Richardson Number float (RiNo) acquired data for eleven days in ring center.

This report documents the work performed at sea, and summarizes some of the data collected.

Overview

The scientific objective of the Warm Ring Inertial Critical Layer Experiment (WRINCLE) was to study the phenomenon of inertial-internal wave trapping in anticyclonic rings and the associated mixing expected to occur where the wave shear becomes strong in the thermocline. This experiment was conducted on the R/V Oceanus between March 20 and April 9, 1990.

An essential element of the project was to locate a robust warm core ring of the Gulf Stream. Unfortunately, 1990 seemed to have an anomalously low population of warm rings. In the months before the cruise only a few weak warm eddies were observed in the slope waters between Cape Cod and Virginia. The latest satellite imagery at cruise time showed only weak eddies south of Cape Cod but a fairly strong, recently formed ring well to the east. The eastern ring was the more desirable target. However, it had moved north so that part of it occupied Canadian territorial waters and permission for research there had not been obtained. Just before departure, though, a request was initiated to the Canadian Government through the U.S. State Department for clearance. Since this seemed a high probability and a good fraction of the ring was outside their waters, we sailed to the east. We did in fact receive clearance two days later, in good time to allow a wider area XBT survey. Figure 1 shows the experimental area with the location and direction of movement of the ring center during WRINCLE.

On approaching the site indicated by the satellite images the warm core ring was located by an XBT survey. Then, because conditions were too rough for float or profiler work, an eXpendable Current Profiler (XCP) survey of the ring interior was completed. The weather improved, and the Richardson Number Float (RiNo) was deployed for a brief ballast and tracking test, and a test of the High Resolution Profiler (HRP) was completed. The RiNo was then deployed in ring center with 14-day time limit and target depth of 450 m. HRP casts were completed following RiNo as it moved with the water near ring center.

Data from the HRP, XCP's and CTD were analyzed after each cast, and used to develop subsequent sampling strategy. As the experiment progressed, larger scale surveys were performed to gather data on the outer regions of the ring. Another XCP survey, large and small scale HRP surveys, two orthogonal CTD transits, and another XBT survey were completed before RiNo had to be recovered in order to have a timely return to Woods Hole. The science party participating in the WRINCLE program is listed below, with affiliation, and general area of responsibility:

Dr. Raymond W. Schmitt	WHOI	Chief Scientist	HRP
Dr. Albert J. Williams	"	Sr. Scientist	RiNo
Dr. John M. Toole	"	Assoc. Scientist	HRP
Dr. Richard L. Koehler	"	Res. Spec.	HRP
Ms. Ellyn Montgomery	"	Res. Assoc.	HPR
Mr. Allan Gordon	"	Sr. Res. Assist.	RiNo
Ms. Margaret Francis Cook	"	Res. Assist.	HRP
Mr. W. David Wellwood	"	Res. Assist.	HRP
Mr. Kurt Polzin	"	Grad. Student	HRP
Dr. Eric Kunze	Univ. of Washington	Scientist	XCP
Mr. Arthur Bartlett	Univ. of Washington	Engineer	XCP

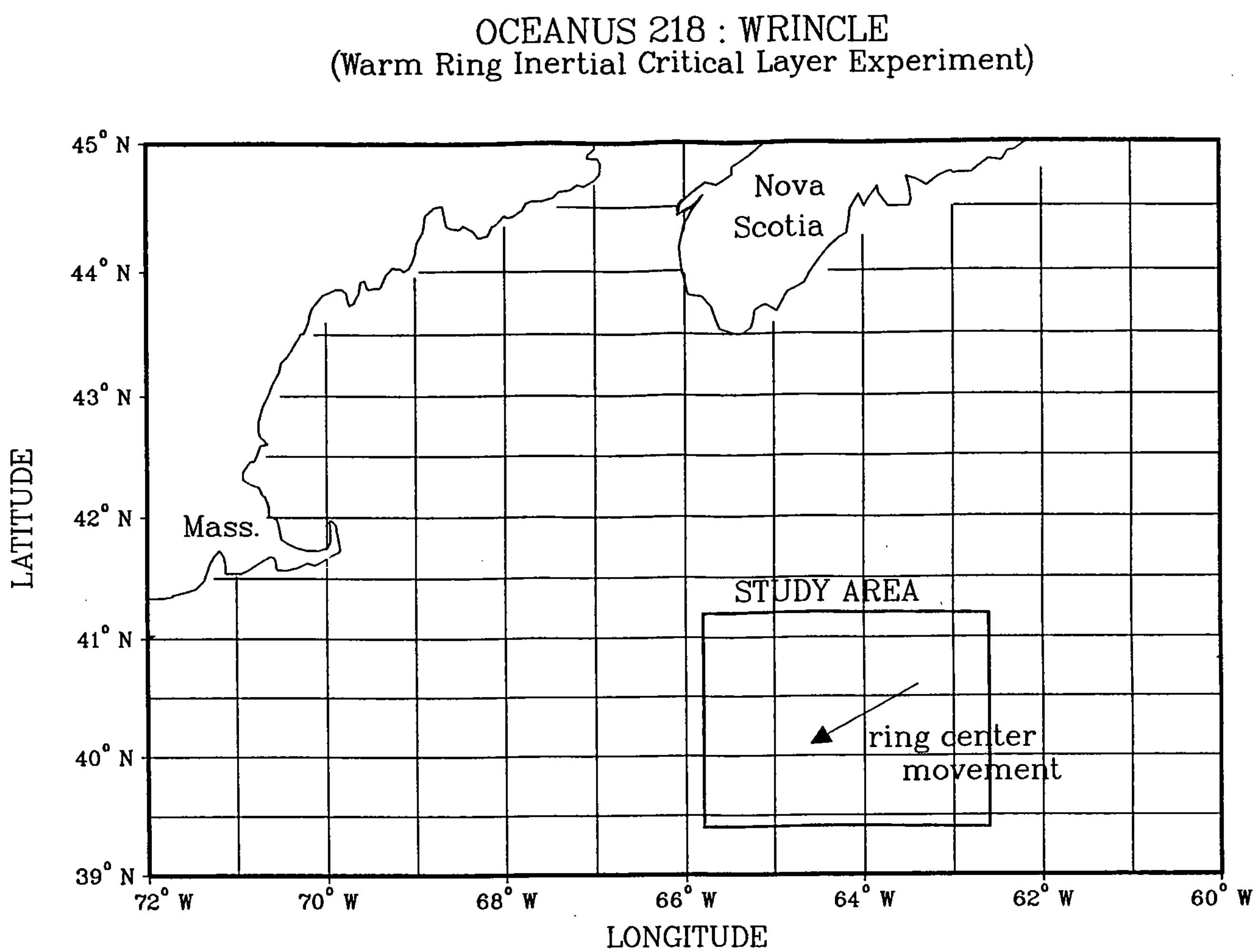

Figure 1: WRINCLE Operational area, with warm core ring location and path shown.

The following sections of this report describe the sequence of events during the cruise, the instrumentation and data acquired.

Cruise Log

At departure time (1300 on March 20) a moderately intense northeaster was moving up the coast. Gale warnings were issued for waters north of our track and we experienced northerly winds in excess of 30 knots most of the first two days. This made for a very uncomfortable acclimatization period for all aboard.

Our first task was to complete an XBT survey that accurately located the center of the ring. We had hoped to get test deployments of the profiler and float en route to the ring, but the sea conditions did not permit that. Thus, our XBT survey began upon our arrival in the area of the ring. A simple zig-zag pattern was performed to delineate the southern boundary (to assure separation from the Gulf Stream) and to sample the thermocline structure in the ring center. This took about 30 hours because of adverse weather, rough seas and the large size of the ring. The ring proved to be quite robust and in the center the thermostad was 300 m thick, with water temperature of about 17°C.

Float and profiler operations were still not possible because of bad weather, so the first eXpendable Current Probe (XCP) survey was performed in ring center on March 23rd. This confirmed that there were large amplitude, high vertical wavenumber horizontal currents in the ring giving quite a morale boost to the scientific party. From March 23rd to 25th initial deployments of the High Resolution Profiler (HRP) and Richardson Number float (RiNo) were made. RiNo had to be fine-tuned in its ballasting, and several components had to be brought to full functionality. After the third launch of RiNo on the 25th, it was left in the central portion of the ring to collect data for the duration of the experiment. Similarly, the first several dives of HRP were primarily for testing and development of launch and recovery skills. Unfortunately, a freak accident on the second recovery damaged one of the acoustic velocity probes. Temporary repairs by Chief Engineer Barrett McLaughlin allowed us to carry on with one of the two current meter channels. The data loss does not appear to be serious, as the accelerometer records can be used to calculate the ocean velocity profiles to a high degree of accuracy. In the early dives we tested different mounts for the shear probes for the measurement of turbulence to determine the lowest noise configuration.

The majority of the HRP dives were done in close proximity to RiNo, which was drifting at about 700 m depth. RiNo was tracked by two methods of acoustic ranging, one short range (12 kHz) and the other (at 1.5 kHz) for long range. The short range tracking was implemented via the ship's transducer or a separate shallow transducer and was recorded on the ship's depth recorder (as was the tracking for HRP). The long range tracking entailed lowering a transducer to 500 to 700 m depth to get it into the sound channel. Range was determined by a precision time base. We found that the long range tracking served to locate RiNo to within a few kilometers; maneuvering the ship using the short range system could reduce the slant range to be equal to the telemetered depth, i.e., right over the float. This gave us the confidence to leave RiNo for later HRP surveys. We planned to retrieve it on April 6; its backup timer release was set for April 8th.

The HRP dives confirmed that there was strong high wavenumber velocity structure in the thermocline. It also showed very strong mixing in the thermocline, a part of the water column that typically exhibits very weak mixing outside of warm core eddies. The performance of the microstructure probes for temperature, conductivity and shear was better than expected, no probe failures were experienced in the cruise, though some selection of shear probes was done to minimize thermal response. After an initial orientation period, the HRP operations were organized into two 12-hour watches with three on each team. Launches, tracking and recoveries became fairly routine and went round the clock. Fairly severe weather conditions (snow, sleet, sea smoke, 20–30-knot winds and 6–10-foot seas) failed to curtail HRP operations. This is unusual for microstructure instruments of this complexity, since the handling of large objects with delicate sensors has not previously been a routine procedure. The special launch and recovery rig built for the HRP made the dives nearly as routine as CTD casts. The capability of working in severe weather added an extra bonus to our data set; we were able to observe significant deepening of the mixed layer in the ring during a cold air outbreak. Warm rings experience particularly high heat losses because of the strong air–sea temperature difference (nearly 20°C at times!). The heavy-weather-capable HRP provided direct observations of both fine- and micro-structure during severe winter-time cooling events.

After several days of work near RiNo, we performed a local area survey around it for two days. We then relocated RiNo in good time and tracked it intensively for several hours on March 30th. We also took advantage of calm weather to change batteries in the HRP. We found that newly available higher energy alkaline cells provided a significant increase in dive capacity for the HRP. We expect that well over 50 dives to 1000 m could be obtained with one battery pack. From March 31 to April 3 we performed a south to north CTD/HRP section across the ring. Severe weather prevented deployment of the HRP at many of the CTD sites initially. However, calmer conditions on April 2–3 allowed us to obtain the HRP dives that had been missed. After completing the section we relocated RiNo and performed a very small scale HRP survey around its position.

After the small scale HRP survey we commenced a final XBT survey of the ring. Based on the drift of RiNo and a Canadian satellite surface analysis map received by FAX on the Oceanus, we thought that the ring had drifted well to the southwest, and laid out a survey pattern accordingly (a "traditional" 5-pointed star). However, it became apparent during the survey that ring center had not moved as far as expected and the pattern was modified to extend coverage to the east.

At the end of the XBT survey we steamed to relocate RiNo. This was accomplished late in the day of April 5th. An HRP dive was done at that location along with an XCP to permit comparison of velocity profiles from the two instruments. A final XCP survey was performed through the night of the 5th and morning of the 6th. The pattern covered an area of about 25 x 25 nautical miles. This corresponded roughly to the portion of the ring where the depth of the 10° isotherm exceeded 500 m.

After the XCP survey RiNo was again located and called to the surface. It was brought back aboard ship without mishap late in the day on the 6th. Throughout the cruise RiNo could be tracked with reasonable efficiency by use of the long range tones which sounded at the hour. Two fixes usually gave a valid first guess at the location which was then fine-tuned by the short range 12 kHz system. The long range system functioned well to a distance of 60 nm, the greatest range tested. Greater distances should be easily obtained, since the received signal was still quite strong.

With RiNo aboard we steamed to commence a final east to west transect of the ring using HRP and CTD stations. After 4 combined stations the weather deteriorated and only CTD stations could be obtained. Problems with the slip ring mount on the winch and a strong gale curtailed operations entirely the night of April 7–8 as the ship had to heave-to. Diligent work by Bosun Richard Simkins, Chief Engineer Barrett McLaughlin and Dr. Albert J. Williams III served to repair the slip ring mount. Seas had abated enough to make way by 0400 DST on the 8th and we recommenced CTD work. Combined HRP and CTD stations were started at 1000 that day. By deploying the profiler when the CTD was being retrieved, very little extra time was spent on station for the HRP dives. On completion of the east–west section we began steaming for Woods Hole and arrived at 1500 on April 9th.

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Instrumentation Description and Data Summary

To accomplish the goals of this experiment, five types of oceanographic instruments were used: XBT, (eXpendable BathyThermograph) CTD (Conductivity, Temperature and Depth Profiler), XCP (eXpendable Current Profiler), the RiNo (the Richardson Number float), and the HRP (High Resolution Profiler). The first three listed are commonly used in oceanography and are manufactured products. The Richardson Number float and High Resolution Profiler are single free vehicle instruments developed at the Woods Hole Oceanographic Institution to perform specialized data collection tasks. The RiNo is neutrally buoyant and can sample at 2 Hz for a single long deployment, interspersed with more rapid sampling bursts triggered by external stimuli. The HRP samples at 10 and 200 Hz, as it falls through the water column. It can be deployed, recovered, data downloaded, and prepared for the next cast with a cycle time of as little as two hours for a 1000 m cast.

XBT surveys were completed to locate the ring and provide isotherm depth information. CTD stations were done along North–South and East–West transect lines to provide data for comparison with the High Resolution Profiler's CTD, and to acquire data deeper than the HRP casts provided (1000 m). The Richardson Number (RiNo) float was deployed at 480 m in ring center based on the XBT data. The RiNo float is neutrally buoyant, and so tracked the parcel of water in which it was deployed. RiNo collected 11.5 days of data before it was recovered. Two (XCP) surveys were performed during the cruise, using 55 XCPs. The surveys were completed 14 days apart, each nominally at ring center, with the second survey covering a larger horizontal area than the first. The HRP completed the suite of instruments sampling the ring. Profiler casts were done in ring center, along North–South and East–West transects, and in small-scale grids to allow examination of the horizontal extent of observed features. A total of 78 HRP casts were completed on OC218. A mishap during recovery on cast 2 disabled the X current measurement axis, but aside from that, the HRP functioned well.

The following sections describe the data sets collected by each instrument type, starting with the HRP, and followed by XCP, RiNo, CTD and XBT.

HRP

The High Resolution Profiler is a free vehicle designed to acquire and log oceanic fine- and micro-structure data; it was first used in FASINEX (Frontal Air–Sea Interaction Experiment) in 1986. A schematic of the HRP is shown in Figure 2. For additional information on the development of the HRP, see the paper by Schmitt *et al.*, 1987, and for operational details of the HRP see the technical report by Montgomery (1991). The following is a brief description of the HRP and its capabilities. The HRP has two profiling modes: fine and micro, with the transition between them triggered by the CTD's pressure reaching user-defined threshold values. Fine sensors (including the CTD) are sampled at 10 Hz, and microstructure sensors are sampled at 200 Hz, with fine sampling continuing throughout the period of micro sampling. Up to 16 sensors may be carried on the HRP to complement the basic CTD measurements. Data is acquired and stored internally in a 16 MB RAM (Random Access Memory) mass storage device as the profiler descends through the water column. The data is removed from memory when the HRP is back on deck after the profile is completed. The sensor configuration used during OC218 was the following:

	A/D channel	offset	multiplier	divisor
fine sensors				
pressure	0	0	1	10
temperature	0	0	1	2000
conductivity	0	0	1	1000
accelerometer, top X	0	0	1	1
accelerometer, top Y	1	0	1	1
accelerometer, bottom X	2	0	1	1
accelerometer, bottom Y	3	0	1	1
acoustic current meter, X velocity	4	0	1	1
acoustic current meter, Y velocity	5	0	1	1
X magnetometer	6	0	1	1
Y magnetometer	7	0	1	1
A/D ground	14	0	1	1
micro sensors				
micro conductivity	10	0	1	1
micro temperature	11	0	1	1
shear X	12	0	1	1
shear Y	13	0	1	1

A typical cast on OC218 acquired fine data to 1000 m, and had microstructure data associated with it from 50–1000 m. Table 1 provides a list of the dates, locations and depth ranges of the HRP casts. Figure 3 shows a chart of where the sampling occurred. A sample of the CTD data acquired on HRP cast 72 is shown in Figure 4. This cast was done at nominally the same time and position as CTD 16 (Figure 12); the correspondence between the data from these two casts is very good. Figure 5 shows the accelerometer data (ax - ay top and bx - by bottom), Figure 6 shows the magnetometer data (hx - hy) Figure 7 shows the plot of microstructure data from cast 72.

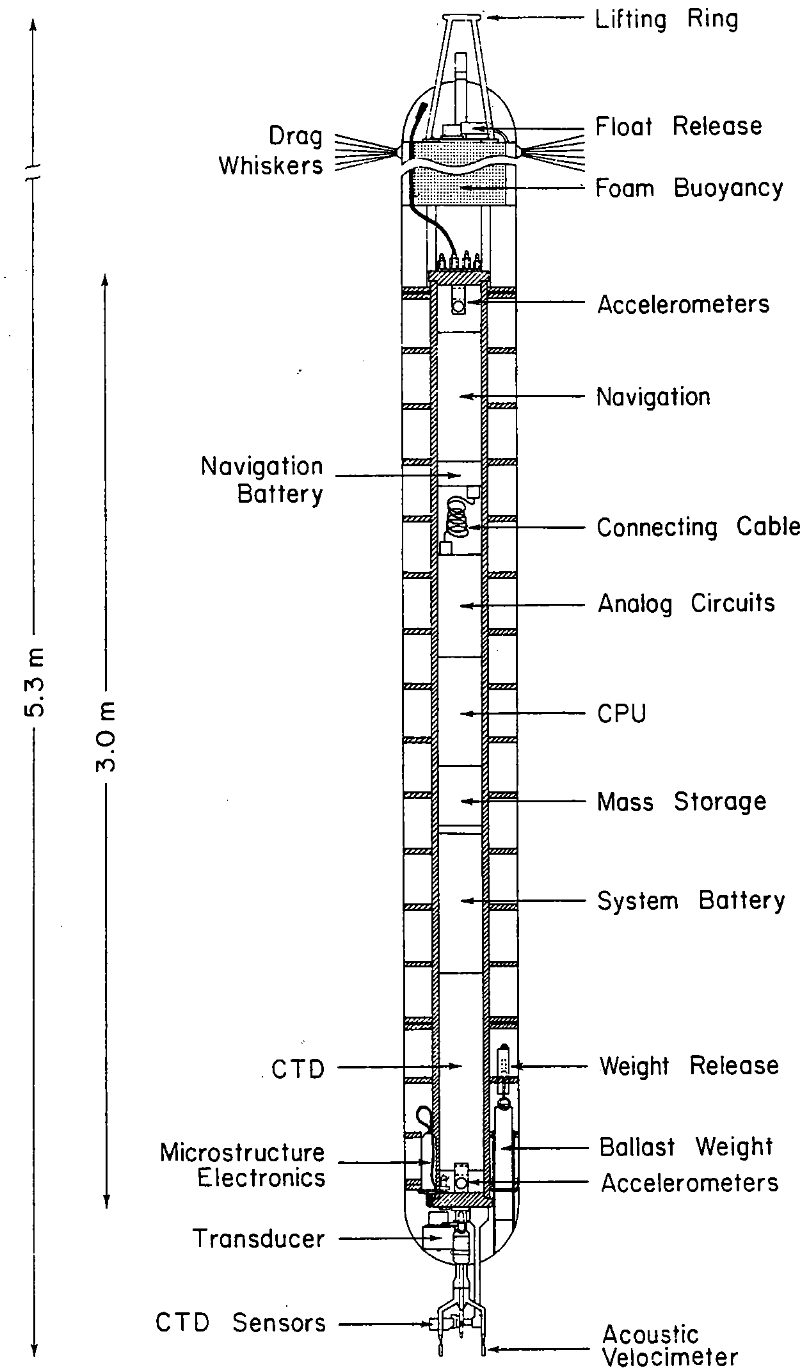

Figure 2: Schematic of the High Resolution Profiler.

TABLE 1: OCEANUS 218: High Resolution Profiler (HRP) Drops

Drop #	Date M/D/Y	Time GMT	Position Lat. °N	Long. °W	Max. Fine Pres. (db)	Micro Range (db)	Comments
1	3/23/90	1438	40.436	63.616	750	25–750	test nr. ring cntr.
2	3/23/90	1910	40.445	63.611	1000	50–1000	damaged ACM
3	3/24/90	1852	40.634	63.618	1000	50–1000	used 2 shear probes
4	3/24/90	2227	40.653	63.612	1000	50–1000	
5	3/24/90	2323	40.667	63.578	1000	50–1000	
6	3/25/90	0158	40.672	63.514	1000	50–1000	
7	3/25/90	0426	40.607	63.471	1000	50–1000	changed shear probes
8	3/25/90	1903	40.559	63.448	1000	40–1000	changed shear probes
9	3/25/90	2116	40.559	63.448	1000	40–1000	
10	3/26/90	0108	40.563	63.459	1000	40–1000	
11	3/26/90	0520	40.541	63.473	1000	40–1000	
12	3/26/90	1001	40.562	63.445	1000	50–1000	near RiNo
13	3/26/90	1154	40.567	63.437	1000	50–1000	
14	3/26/90	1346	40.494	63.507	1000	50–1000	early return surface
15	3/26/90	1633	40.476	63.508	1000	50–1000	
16	3/26/90	1915	40.461	63.528	1000	50–1000	
17	3/26/90	2214	40.444	63.509	1000	40–1000	
18	3/27/90	0039	40.433	63.568	1000	40–1000	
19	3/27/90	0326	40.418	63.594	1000	40–1000	
20	3/27/90	0636	40.412	63.595	1000	40–1000	tape on ACM struts
21	3/27/90	0944	40.491	63.593	1000	50–1000	
22	3/27/90	1219	40.379	63.657	1200	50–1200	fine overwrote header.
23	3/27/90	1642	40.361	63.650	1000	50–1000	replace radio battery install rigid shear probe support
24	3/27/90	1850	40.360	63.683	1000	50–1000	
25	3/27/90	2159	40.344	63.674	1000	40–1000	
26	3/28/90	0059	40.394	63.674	1000	40–1000	broke weld on bail
27	3/28/90	0407	40.323	63.674	1000	40–1000	
28	3/28/90	1041	40.331	63.759	1000	40–1000	install ACM/CTD tie
29	3/28/90	1805	40.277	63.788	1000	40–1000	
30	3/28/90	2043	40.279	63.795	1000	40–1000	
31	3/29/90	0010	40.277	63.795	1000	40–1000	
32	3/29/90	0310	40.276	63.795	1000	40–1000	remove tape & tie
33	3/29/90	0710	40.276	63.795	1000	40–1000	
34	3/29/90	0912	40.248	63.876	1000	40–1000	RiNo box patrn #1
35	3/29/90	1125	40.084	63.868	1000	40–1000	" " #2
36	3/29/90	1412	39.908	63.886	1000	40–1000	" " #3
37	3/29/90	1620	39.916	64.037	1000	25–1000	" " #4
38	3/29/90	1845	39.912	64.209	1000	25–1000	no more deployment floats
39	3/29/90	2203	40.082	64.199	1000	40–1000	" " #6
40	3/30/90	0054	40.250	64.200	1000	25–1000	" " #7

OCEANUS 218: **High Resolution Profiler (HRP) Drops** (Continued)

Drop #	Date M/D/Y	Time GMT	Position Lat. °N	Position Long. °W	Max. Fine Pres. (db)	Micro Range (db)	Comments
41	3/30/90	0225	40.421	64.195	1000	40–1000	test pres. release
42	3/30/90	0642	40.416	64.032	1000	40–1000	RiNo box #9
43	3/30/90	0833	40.413	63.863	1000	25–1000	" #10
44	3/30/90	1038	40.246	64.033	1000	25–1000	" #11
45	3/30/90	1230	40.081	64.034	1000	10–1000	last in RiNo box
46	3/31/90	0105	40.162	64.125	1000	40–1000	new battery
47	3/31/90	0543	39.557	64.257	1000	40–1000	30 kt. winds
48	4/01/90	1456	40.767	64.246	1000	25–1000	N. side of ring
49	4/01/90	1939	40.898	64.249	1000	25–1000	changed. shear X
50	4/02/90	0203	41.033	64.250	1000	40–1000	
51	4/02/90	0638	41.165	64.249	1000	40–1000	
52	4/02/90	1040	40.632	64.250	1000	25–1000	CTD stn. 9
53	4/02/90	1313	40.499	64.250	1000	25–1000	" 8
54	4/02/90	1458	40.369	64.250	1000	25–1000	" 7
55	4/02/90	1632	40.230	64.253	1000	25–1000	" 6
56	4/02/90	1911	40.580	64.251	1000	40–1000	" 5
57	4/02/90	2143	39.968	64.250	1000	40–1000	" 4
58	4/02/90	1339	39.807	64.251	1000	40–1000	" 3
59	4/03/90	0123	39.666	64.250	1000	40–1000	" 2
60	4/03/90	1447	40.112	64.528	1000	25–1000	start small survey
61	4/03/90	1637	40.118	64.555	1000	25–1000	
62	4/03/90	1805	40.115	64.574	1000	25–1000	
63	4/03/90	1932	40.155	64.518	1000	25–1000	
64	4/03/90	2113	40.143	64.517	1000	25–1000	
65	4/03/90	2239	40.133	64.519	1000	40–1000	
66	4/04/90	0022	40.116	64.518	1000	40–1000	
67	4/04/90	0207	40.103	64.519	1000	40–1000	
68	4/04/90	0409	40.088	64.517	1000	40–1000	
69	4/04/90	0536	40.075	64.516	1000	40–1000	
70	4/05/90	2321	40.194	64.710	1000	40–1000	RiNo pre-recovery
71	4/07/90	0005	40.233	63.617	950	40– 950	start E–W section Corresponds to 27 test weight release CTD stn 15
72	4/07/90	0649	40.233	63.843	1000	40–1000	" 16
73	4/07/90	1009	40.210	64.035	1000	25–1000	" 17
74	4/07/90	1325	40.189	64.192	1000	25–1000	" 18
75	4/08/90	1404	40.248	65.050	1000	25–1000	" 23
76	4/08/90	1647	40.251	65.246	1000	25–1000	" 24
77	4/08/90	1925	40.233	65.453	1000	40–1000	" 25
78	4/08/90	2212	40.228	65.677	1000	40–1000	" 26

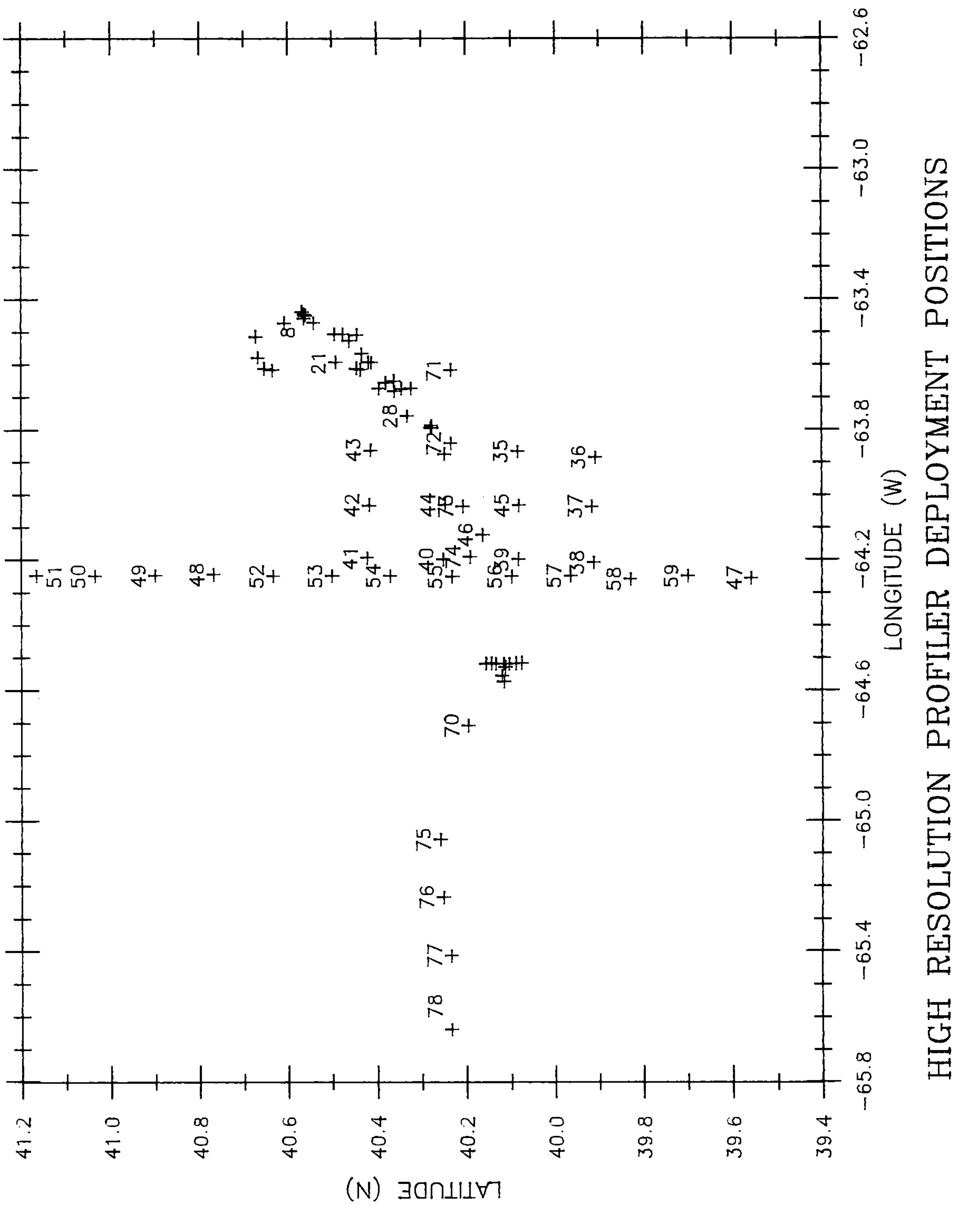

Figure 3: Chart showing locations of HRP casts.

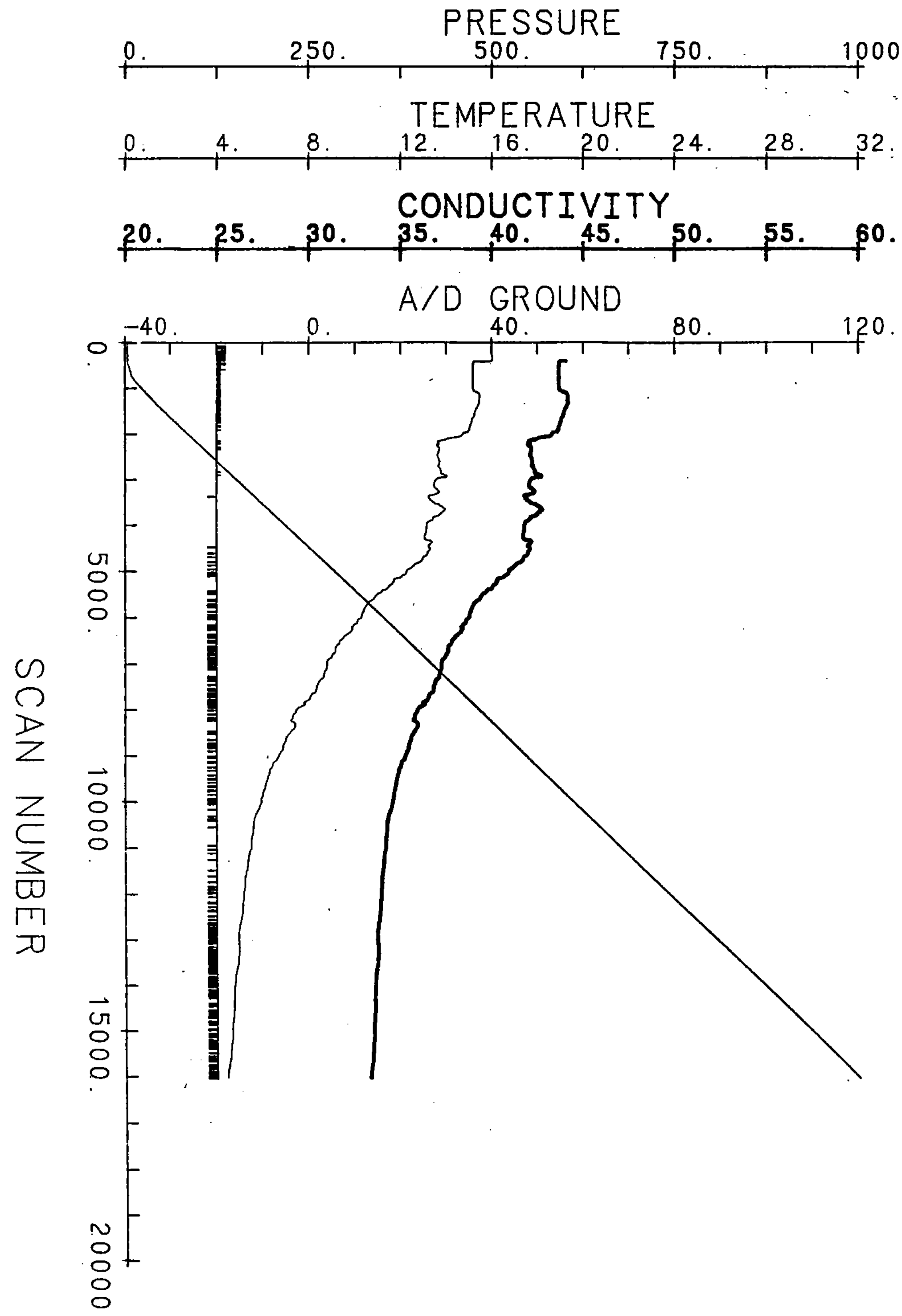

Figure 4: Temperature, conductivity and pressure records from HRP cast 72.

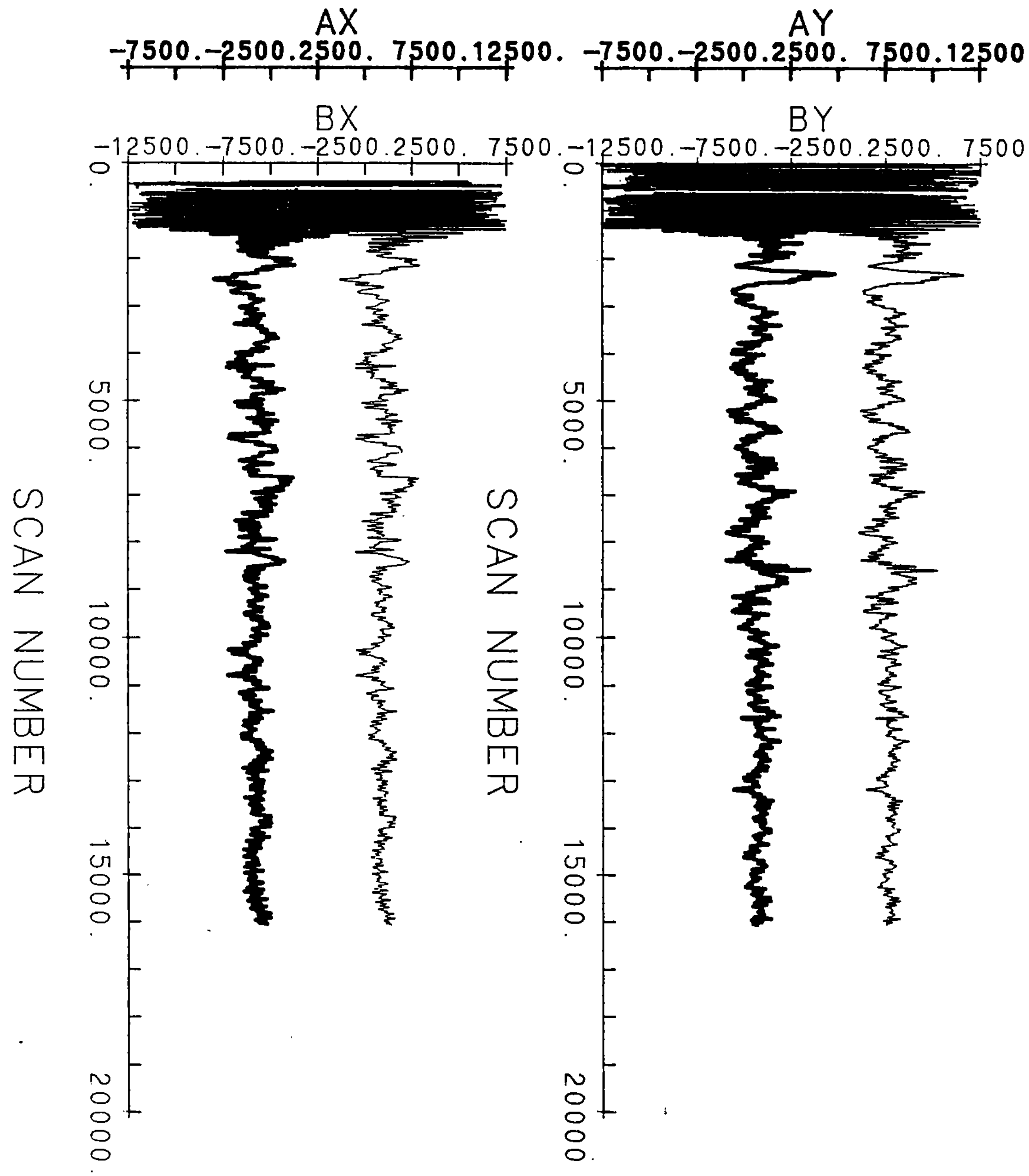

Figure 5: Accelerometer data (top and bottom pairs) from HRP cast 72.

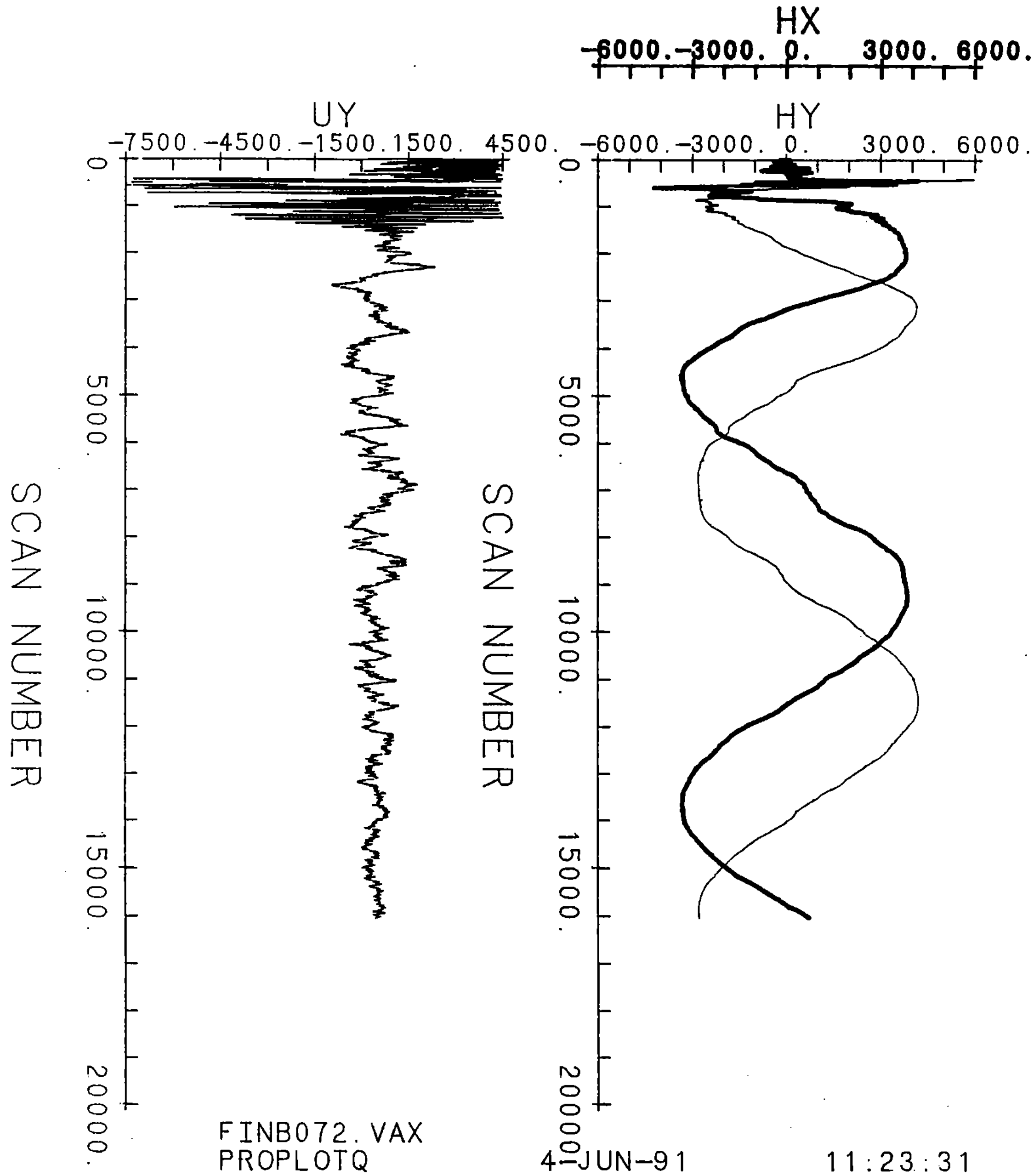

Figure 6: Sample magnetometer and acoustic current meter data from HRP cast 72.

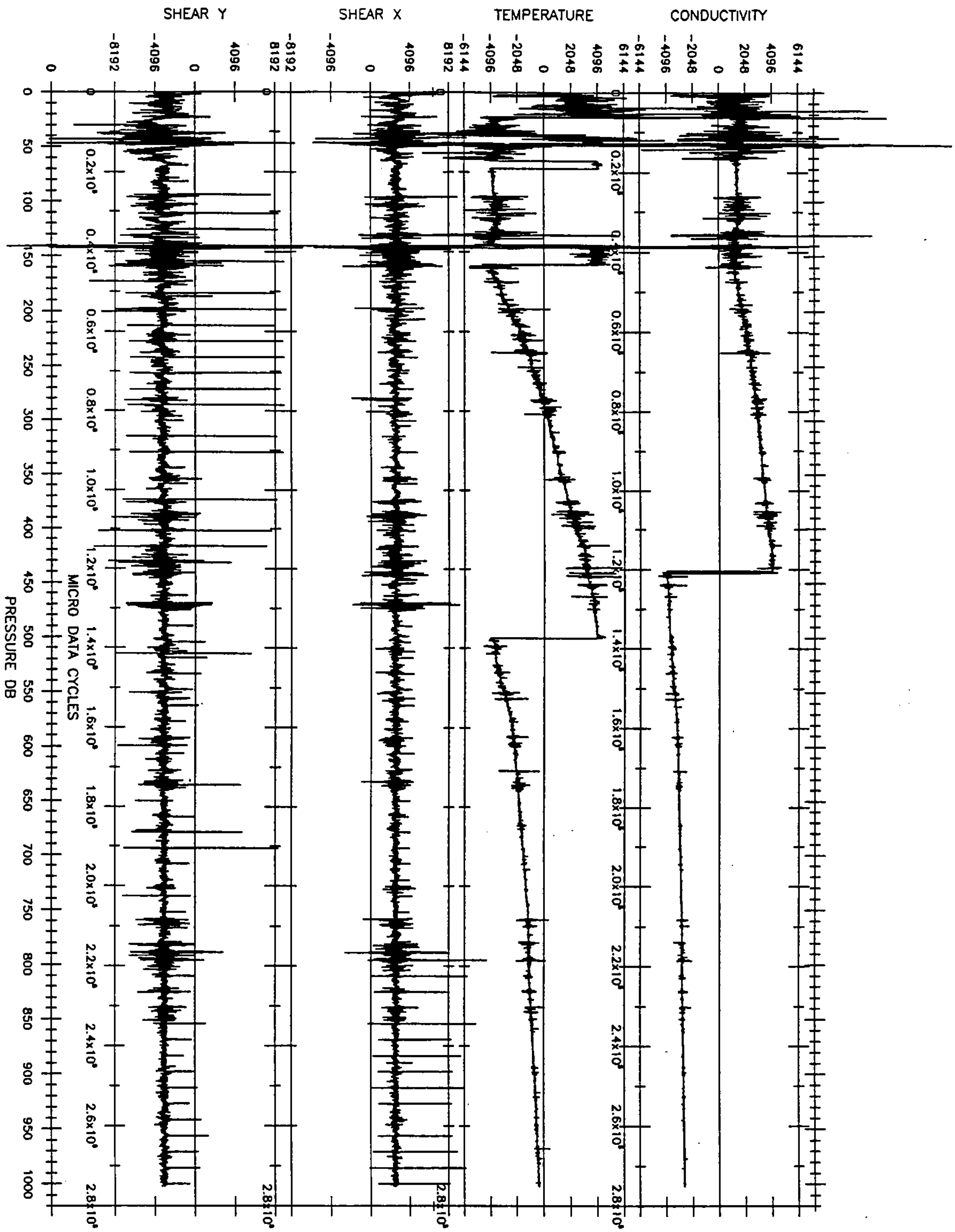

Figure 7: Sample microstructure plot from HRP cast 72.

XCP

XCPs are devices that make high quality, rapid measurements of ocean current speed to a depth of 1600 m. Surveys using XCPs allow analysis of upper ocean circulation at the time of the survey. Table 2 shows the times and locations of the two XCP surveys completed during OC218. Figure 8 is a chart of the XCP drop positions. XCP drop 27 was done at the same time as HRP 56. The velocity derived from the HRP accelerometers plotted against the measured velocities from the XCP are shown in Figure 9.

TABLE 2: Warm Ring Inertial Critical-Layer XCP Drop Positions

Drop #	Date M/D/Y	Time GMT	Position Lat. °N	Long. °W
001	3/23/90	0515	40.535	63.587
002	3/23/90	0522	40.537	63.535
003	3/23/90	0538	40.548	63.508
004	3/23/90	0554	40.535	63.465
005	3/23/90	0603	40.537	63.437
006	3/23/90	0610	40.541	63.413
007	3/23/90	0623	40.537	63.383
008	3/23/90	0633	40.515	63.380
009	3/23/90	0648	40.483	63.320
010	3/23/90	0659	40.458	63.365
011	3/23/90	0714	40.428	63.355
012	3/23/90	0723	40.376	63.408
013	3/23/90	0729	40.365	63.403
014	3/23/90	0743	40.352	63.433
015	3/23/90	0802	40.335	63.492
016	3/23/90	0817	40.352	63.540
017	3/23/90	0835	40.335	63.592
018	3/23/90	0906	40.378	63.645
019	3/23/90	0928	40.432	63.655
020	3/23/90	0946	40.473	63.645
021	3/23/90	1015	40.488	63.588
022	3/23/90	1052	40.495	63.530
023	3/23/90	1135	40.493	63.445
024	3/23/90	1207	40.447	63.437
025	3/23/90	1235	40.432	63.493

TABLE 2: Warm Ring Inertial Critical-Layer XCP Drop Positions (Continued)

Drop #	Date M/D/Y	Time GMT	Position Lat. °N	Position Long. °W
026	3/23/90	1259	40.418	63.562
027	4/6/90	2322	40.195	64.710
028	4/6/90	0049	40.293	64.713
029	4/6/90	0121	40.398	64.707
030	4/6/90	0212	40.420	64.527
031	4/6/90	0250	40.410	64.357
032	4/6/90	0328	40.400	64.198
033	4/6/90	0408	40.298	64.172
034	4/6/90	0434	40.212	64.182
035	4/6/90	0520	40.057	64.195
036	4/6/90	0603	40.018	64.333
037	4/6/90	0626	40.012	64.423
038	4/6/90	0645	40.010	64.500
039	4/6/90	0705	40.005	64.580
040	4/6/90	0742	40.008	64.600
041	4/6/90	0750	40.107	64.610
042	4/6/90	0814	40.180	64.602
043	4/6/90	0835	40.245	64.592
044	4/6/90	0858	40.317	64.583
045	4/6/90	0928	40.340	64.495
046	4/6/90	0948	40.337	64.413
047	4/6/90	1006	40.333	64.333
048	4/6/90	1041	40.252	64.297
049	4/6/90	1140	40.173	64.310
050	4/6/90	1123	40.113	64.320
051	4/6/90	1146	40.087	64.375
052	4/6/90	1201	40.088	64.433
053	4/6/90	1230	40.147	64.465
054	4/6/90	1252	40.205	64.465
055	4/6/90	1308	40.255	64.465

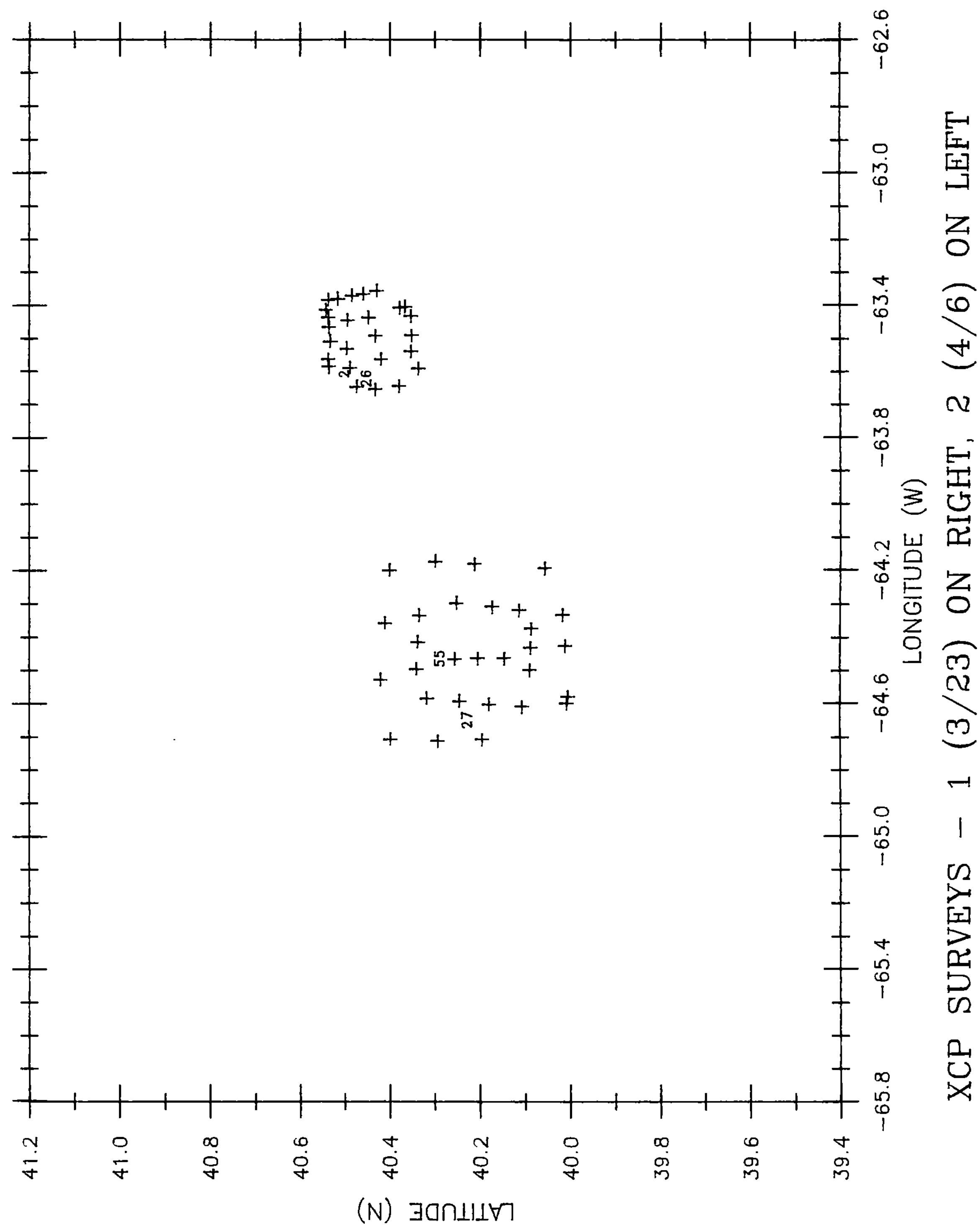

Figure 8: Chart showing of locations of the two XCP surveys.

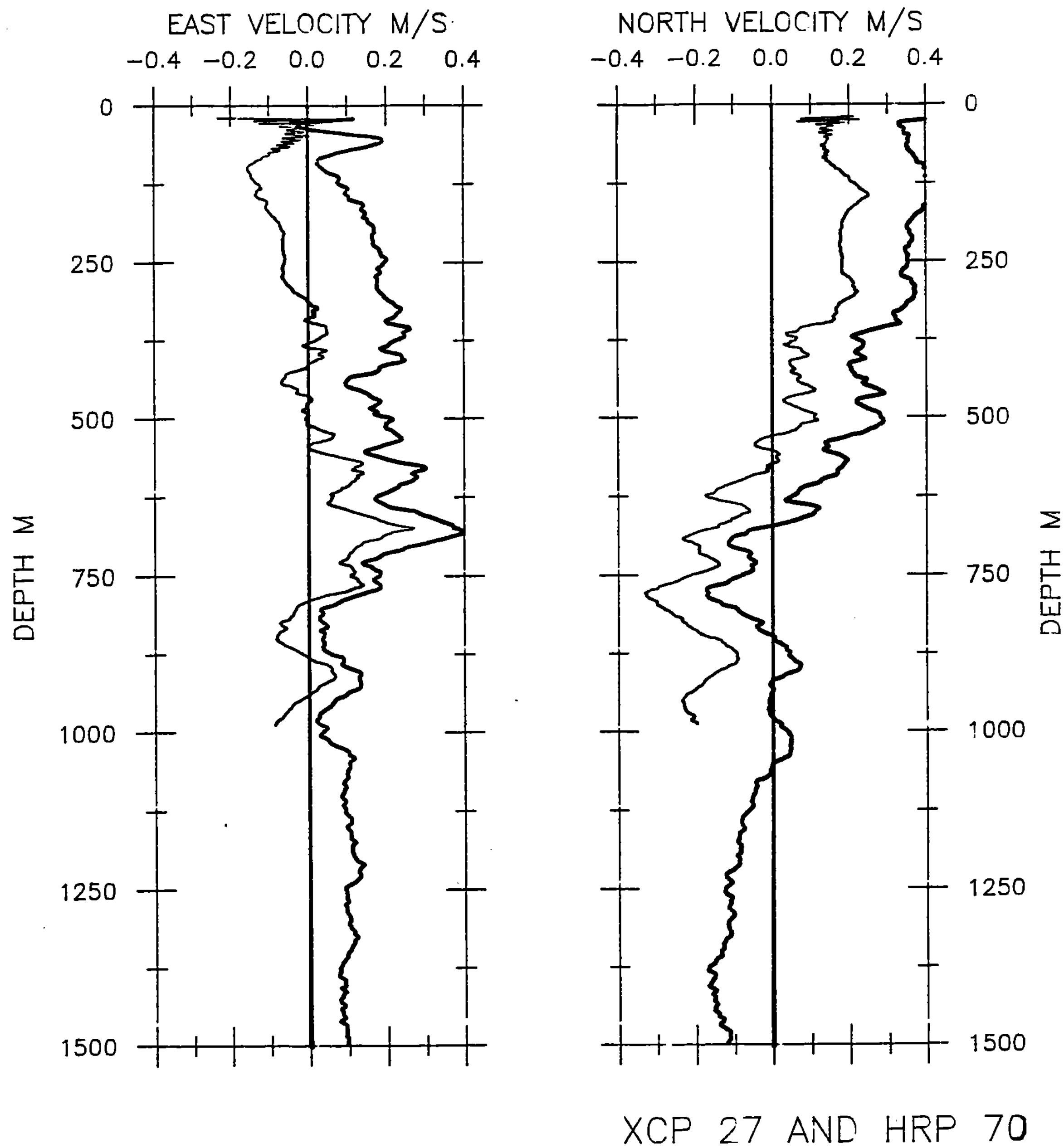

Figure 9: Plot comparing velocity profiles from HRP cast 56 and XCP number 27.

RiNo

The RiNo float was developed to behave like a Swallow float while making high quality current and temperature measurements over its five meter vertical length. Figure 14 is a schematic of RiNo, showing its sensor configuration and shape. RiNo was first used in the Patch Experiment (PATCHEX) in 1986. The technical report by Montgomery (1988) and paper by Williams *et al.* (1987) provide more information on the RiNo. While deployed, RiNo was tracked using a low frequency transponder system. Table 3 shows the deployment, recovery, and tracked positions of RiNo, and Figure 10 shows a chart of RiNo's path.

TABLE 3: Warm Ring Inertial Critical-Layer RiNo Positions

Drop #	Date M/D/Y	Time GMT	Position Lat. °N	Long. °W
001	3/23/90	0515	40.535	63.587
002	3/23/90	0522	40.537	63.565
003	3/23/90	0538	40.548	63.508
004	3/23/90	0554	40.535	63.465
005	3/23/90	0603	40.537	63.437
006	3/23/90	0610	40.542	63.413
007	3/23/90	0623	40.537	63.383
008	3/23/90	0633	40.515	63.380
009	3/23/90	0648	40.483	63.370
010	3/23/90	0659	40.458	63.365
011	3/23/90	0714	40.428	63.355
012	3/23/90	0723	40.377	63.408
013	3/23/90	0729	40.365	63.403
014	3/23/90	0743	40.352	63.433
015	3/23/90	0802	40.335	63.492
016	3/23/90	0817	40.352	63.540
017	3/23/90	0835	40.335	62.592
018	3/23/90	0906	40.378	62.645
019	3/23/90	0928	40.432	62.665
020	3/23/90	0946	40.473	63.645
021	3/23/90	1015	40.488	63.588
022	3/23/90	1052	40.495	63.530
023	3/23/90	1135	40.493	63.445
024	3/23/90	1207	40.447	63.437
025	3/23/90	1235	40.432	63.493
026	3/23/90	1259	40.418	63.562

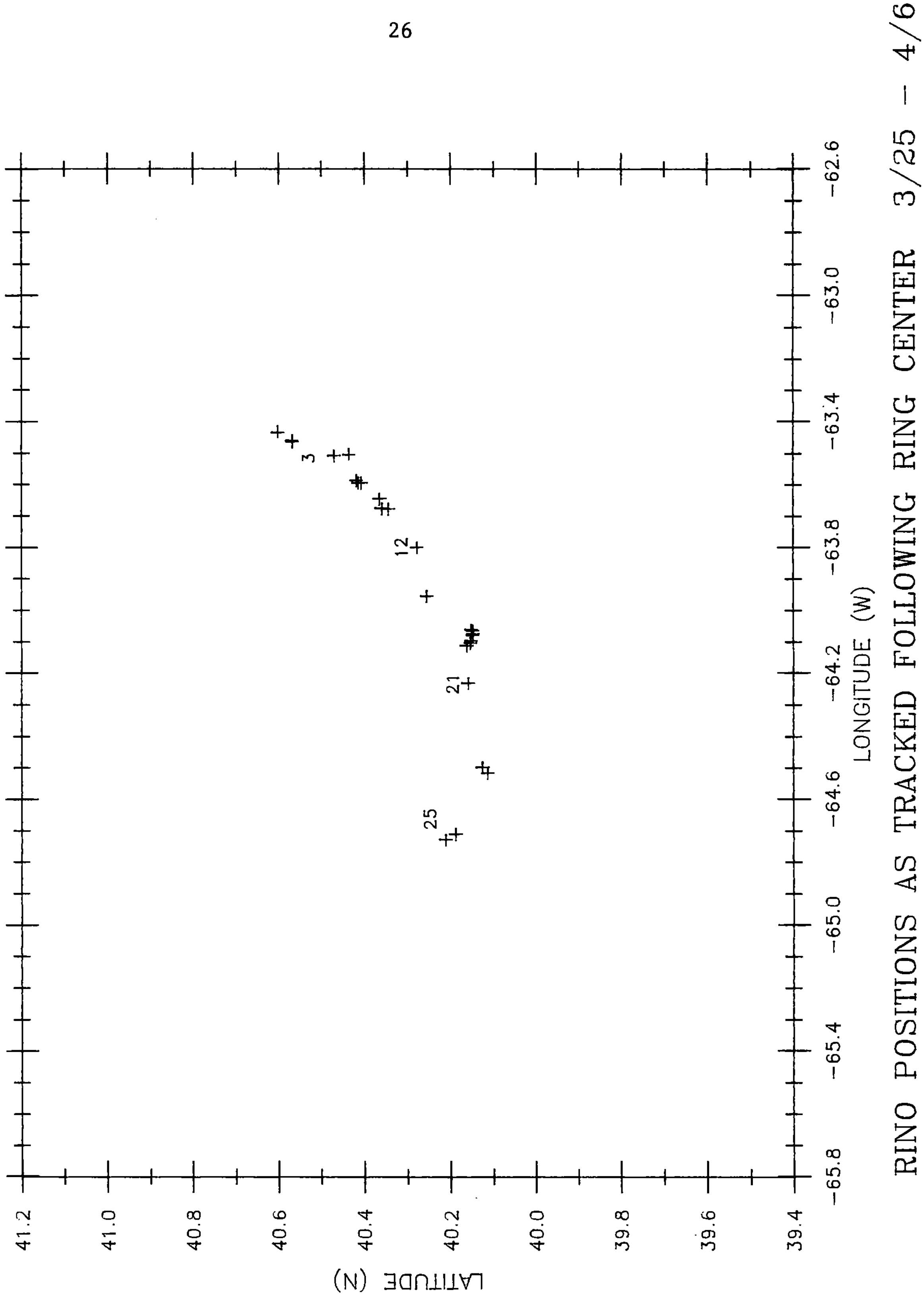

Figure 10: Chart showing RiNo movement during its deployment on OC218.

CTD

The CTD is another ubiquitous oceanographic instrument. It was used on OC218 to provide data for comparison to that acquired by the HRP's CTD, and to acquire data for depths greater than the HRP went. The CTD is a wire-lowered instrument, so there is less potential for losing it on deep casts. Table 4 is a list of the times and locations of the CTD stations. Figure 11 shows the data from cast 16. Many oceanographic parameters are derived from the CTD measurements, and one of the more standard is the T–S curve. Figure 13 shows a scatterplot of the T–S curves from all the CTD stations done on OC218.

Table 4: OCEANUS 218: CTD Station Summary

Station #	Date M/D/Y	GMT Time Start	GMT Time End	Lat. °N	Long. °W	MAX P (db)
1	3/31/90	710	840	39.561	64.261	3519.0
2	3/31/90	1103	1211	39.718	64.247	3431.0
3	3/31/90	1420	1523	39.856	64.266	3515.0
4	3/31/90	1733	1841	39.975	64.258	3523.0
5	3/31/90	2048	2150	40.101	64.254	3515.0
6	04/1/90	12	130	40.236	64.255	3519.0
7	04/1/90	327	444	40.372	64.255	3517.0
8	04/1/90	634	745	40.507	64.256	3505.0
9	04/1/90	936	1052	40.643	64.254	2355.0
11	04/1/90	1607	1724	40.772	64.245	3523.0
12	04/1/90	2022	2138	40.913	64.252	3519.0
13	04/1/90	2331	40	40.033	64.254	3509.0
14	04/2/90	334	445	41.170	64.254	3511.0
15	04/7/90	143	247	40.237	63.627	3507.0
16	04/7/90	432	539	40.237	63.856	3517.0
17	04/7/90	825	930	40.237	64.017	3523.0
18	04/7/90	1147	1257	40.237	64.195	3527.0
19	04/7/90	1509	1605	40.230	64.365	3521.0
20	04/7/90	1739	1841	40.237	64.547	3529.0
21	04/8/90	809	912	40.237	64.729	3533.0
22	04/8/90	1037	1137	40.237	64.901	3539.0
23	04/8/90	1300	1400	40.237	65.068	3521.0
24	04/8/90	1538	1637	40.237	65.242	3517.0
25	04/8/90	1819	1917	40.242	65.416	3511.0
26	04/8/90	2106	2202	40.237	65.652	3509.0

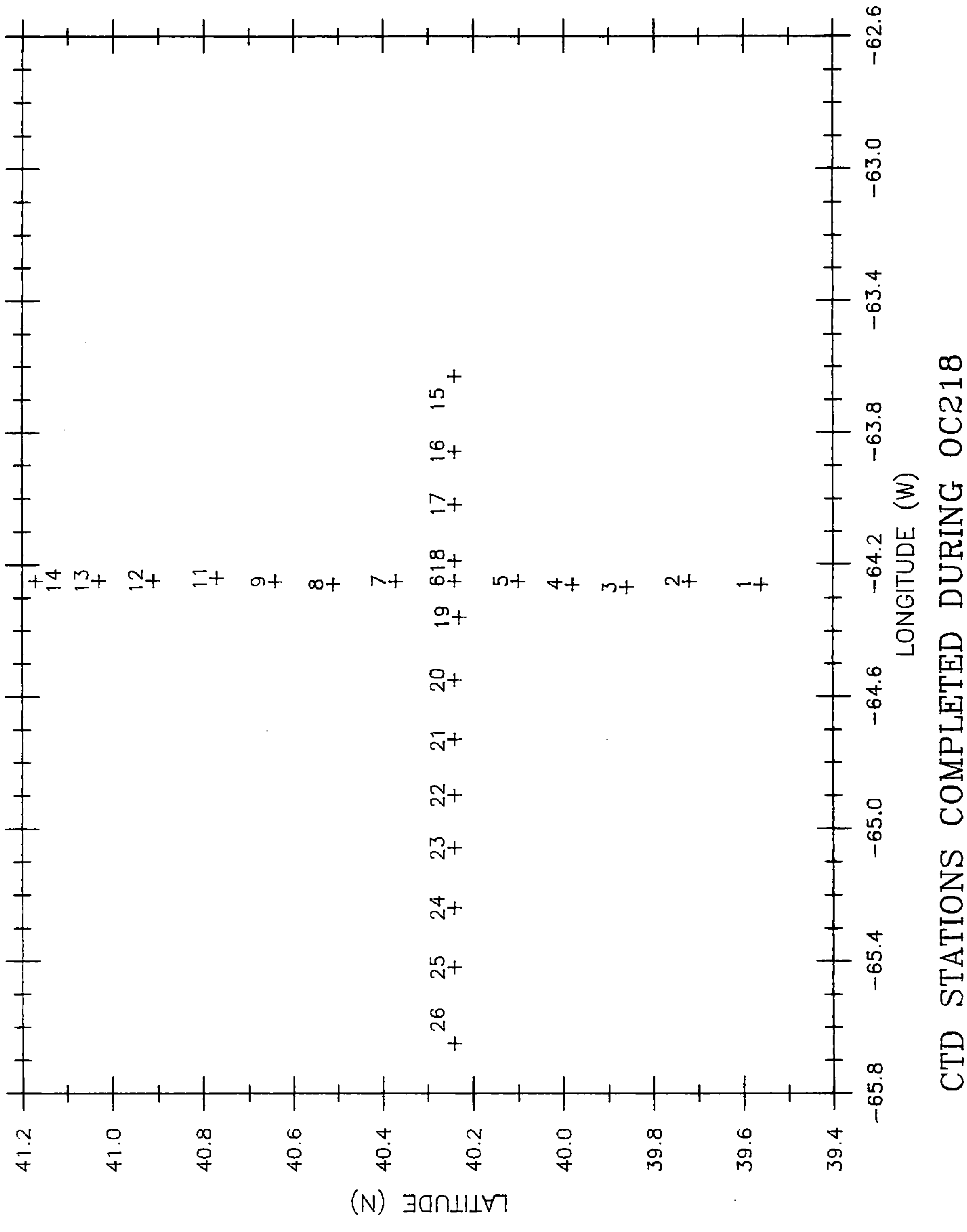

Figure 11: Chart of CTD casts completed on OC218.

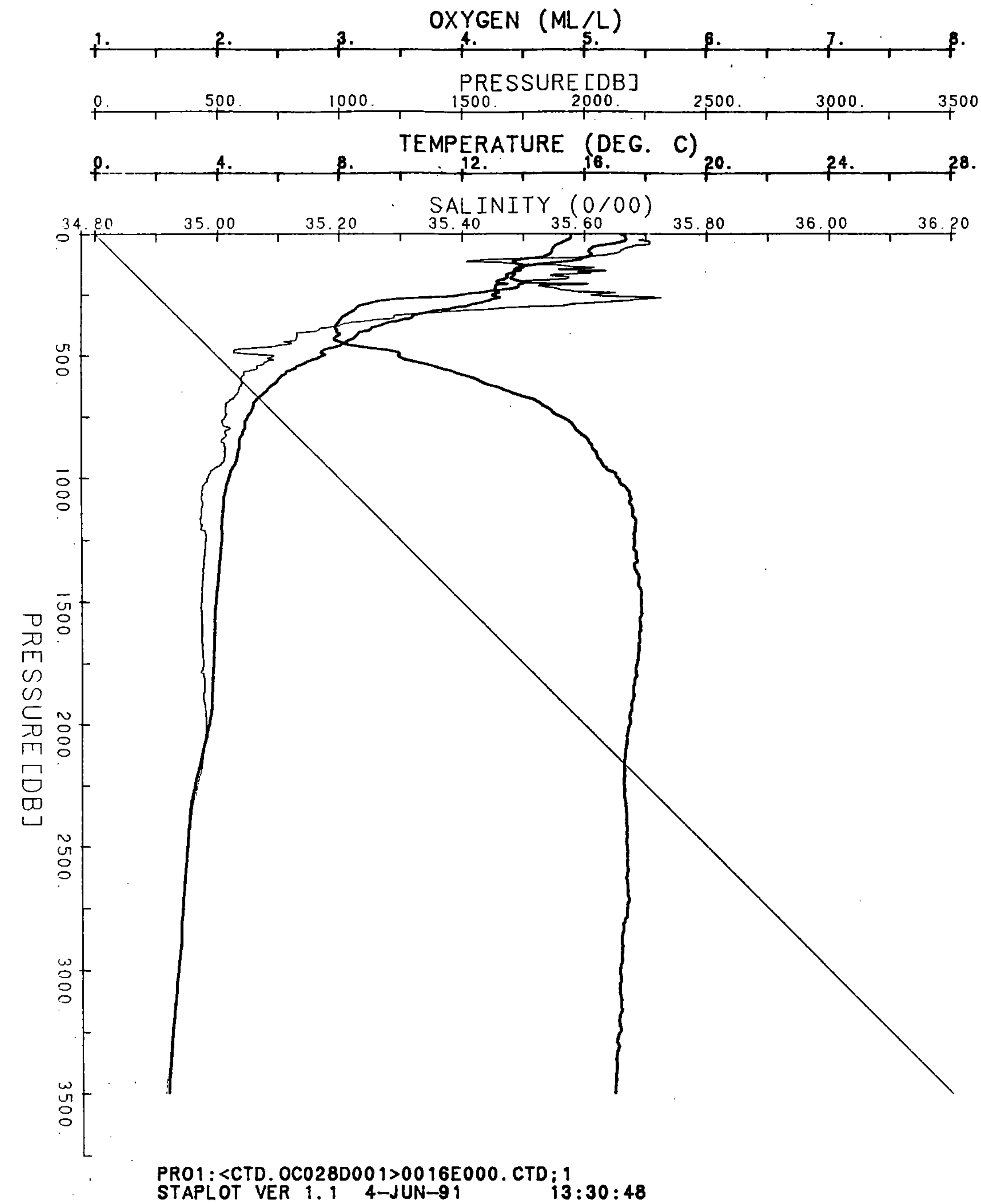

Figure 12: Sample CTD data, from cast 16.

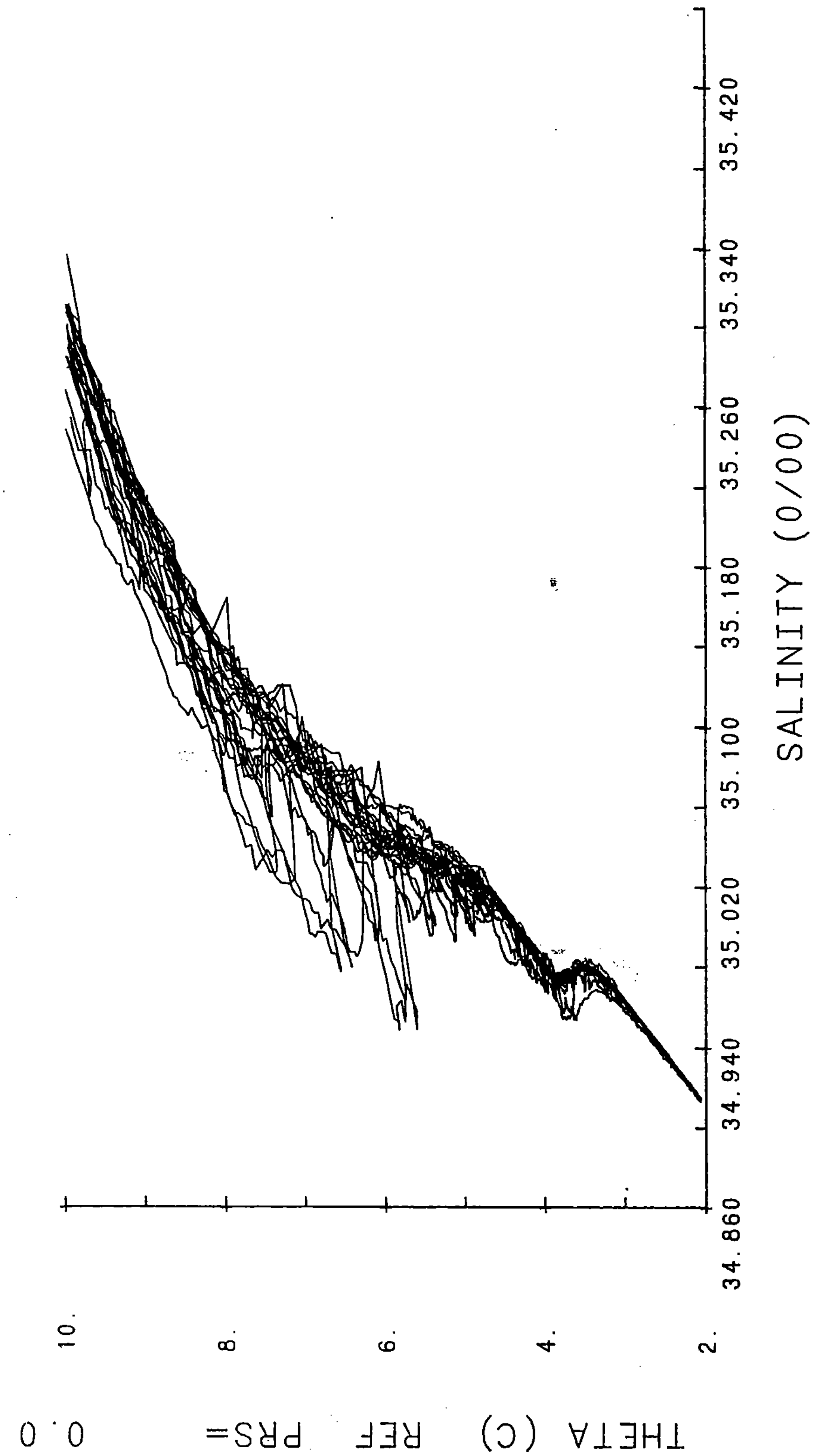

Figure 13: Combined T-S plots from all CTD stations.

XBT

The XBT is a much used instrument that produces a profile of temperature vs depth at the location released. A list of the dates, locations, surface temperature and depth of the ten degree isotherm for each drop is provided in Table 5, and Figures 14 and 15 are charts of the tracks followed during the two XBT surveys. Contour plots are often made to determine the depth and shape of various isotherms. Figure 16 is a plot of the depth of the ten degree isotherm, resulting from XBT survey 2. The center of the ring determined from this plot (for April 5, 1990 approximately 0000h), is nominally 40°22′N, 64°48′W.

TABLE 5: XBT Position Summary

Drop #	Date M/D/Y	Time GMT	Position Lat. °N	Position Long. °W	SST °C	Z10 m	Comments
001	3/21/90	2214	40.100	65.448	8.8	234	Start initial
002	3/22/90	0203	40.067	64.713	10.6	226	survey
003	3/22/90	0353	40.078	64.323	14.9	250	
004	3/22/90	0703	40.082	64.005	19.4	346	
005	3/22/90	0829	40.083	63.798	19.4	377	
006	3/22/90	0845	40.078	63.597	19.4	412	
007	3/22/90	1000	40.082	63.425		430	
008	3/22/90	1120	40.082	63.280	19.0	360	
009	3/22/90	1245	40.078	63.102	17.5	316	
010	3/22/90	1400	40.172	63.170	17.6	358	
011	3/22/90	1600	40.365	63.323	19.4	485	
012	3/22/90	1700	40.485	63.592	19.3	540	
013	3/22/90	1830	40.618	63.825	20.2	459	
015	3/22/90	2015	40.723	63.640	20.3	478	
016	3/22/90	2130	40.723	63.333	19.9	497	
017	3/22/90	2250	40.718	63.012	19.2	460	
018	3/22/90	2350	40.708	62.785	17.5	389	
019	3/23/90	0055	40.613	62.752	17.8	378	
020	3/23/90	0155	40.502	62.983	18.2	446	
021	3/23/90	0300	40.533	63.268	19.2	535	
022	3/23/90	0401	40.491	63.525	18.6	537	pause survey
023	3/24/90	0200	40.302	64.013	18.6	427	continue
024	3/24/90	0314	40.307	64.313	18.8	356	
026	3/24/90	0416	40.502	64.265	18.6	376	
027	3/24/90	0510	40.660	64.272	19.7	378	
028	3/24/90	0634	40.780	63.982	17.5	415	

Continuation – OCEANUS 218: XBT Positions

Drop #	Date M/D/Y	Time GMT	Position Lat. °N	Position Long. °W	SST °C	Z10 m	Comments
029	3/24/90	0754	40.632	63.715	15.2	517	
030	3/24/90	0845	40.548	63.557	18.1	565	end 1st survey
031	4/04/90	0800	39.867	64.667	17.2	401	start 2nd survey
032	4/04/90	0920	39.726	64.909	17.1	279	
033	4/04/90	1048	39.600	65.133	14.0	259	
034	4/04/90	1205	39.828	65.043	16.7	301	
035	4/04/90	1305	40.020	64.970	17.0	356	
036	4/04/90	1355	40.163	64.907	17.4	431	
037	4/04/90	1435	40.289	64.840	17.1	453	
038	4/04/90	1533	40.487	64.756	17.1	433	
039	4/04/90	1638	40.700	64.667	17.1	367	
040	4/04/90	1802	40.497	64.569	16.5	473	
041	4/04/90	1914	40.297	64.492	17.5	540	
042	4/04/90	2004	40.155	64.440	17.7	530	
043	4/04/90	2049	40.030	64.392	17.5	510	
044	4/04/90	2200	39.839	64.310	17.6	420	
045	4/04/90	2330	39.603	64.201	14.6	290	
047	4/05/90	0052	39.730	64.454	17.0	390	
048	4/05/90	0227	39.939	64.808	17.2	420	
049	4/05/90	0416	40.148	65.189	15.1	320	
050	4/05/90	0530	40.283	65.433	14.8	280	
051	4/05/90	0645	40.292	65.143	16.7	360	
052	4/05/90	0844	40.287	64.667	17.2	534	
053	4/05/90	1030	40.285	64.217	17.2	496	
054	4/05/90	1205	40.500	64.008	17.2	410	
055	4/05/90	1312	40.500	63.750	15.8	325	
056	4/05/90	1410	40.325	63.730	16.0	332	
057	4/05/90	1515	40.120	63.750	15.0	336	
058	4/05/90	1707	40.094	64.000	16.1	437	
059	4/05/90	1826	40.110	64.322	17.4	526	End 2nd survey

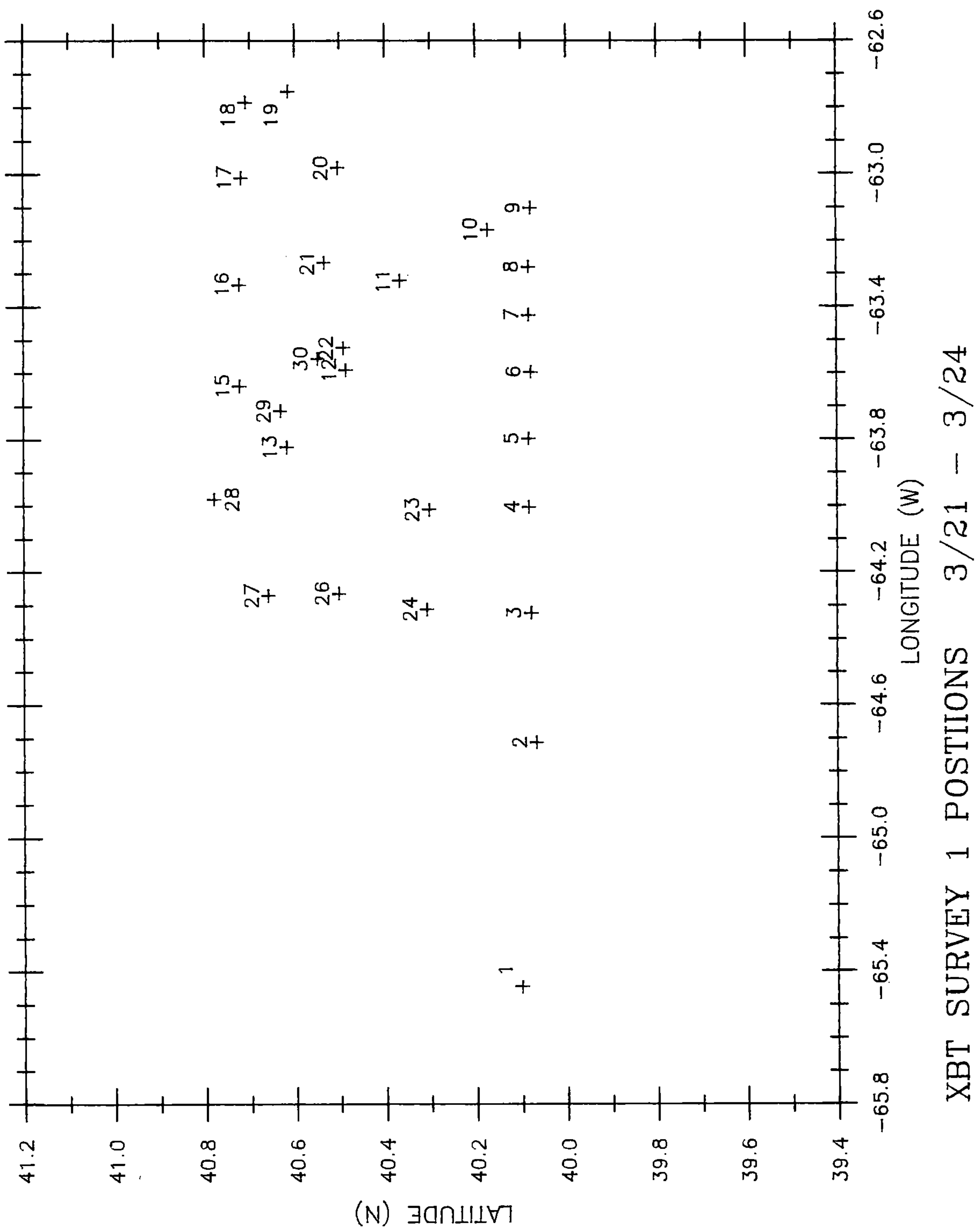

Figure 14: Chart of track followed during XBT Survey 1.

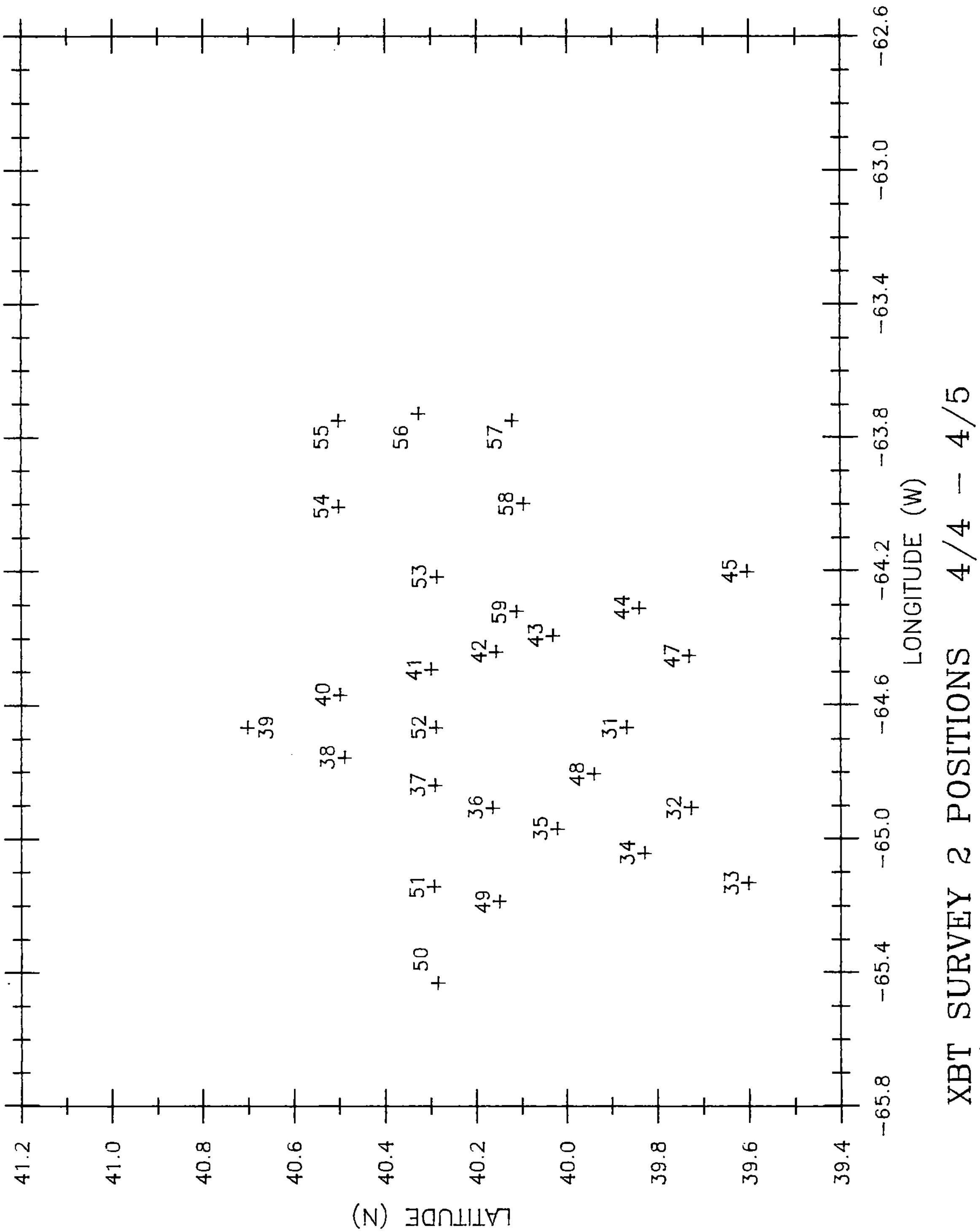

Figure 15: Chart of track followed during XBT Survey 2.

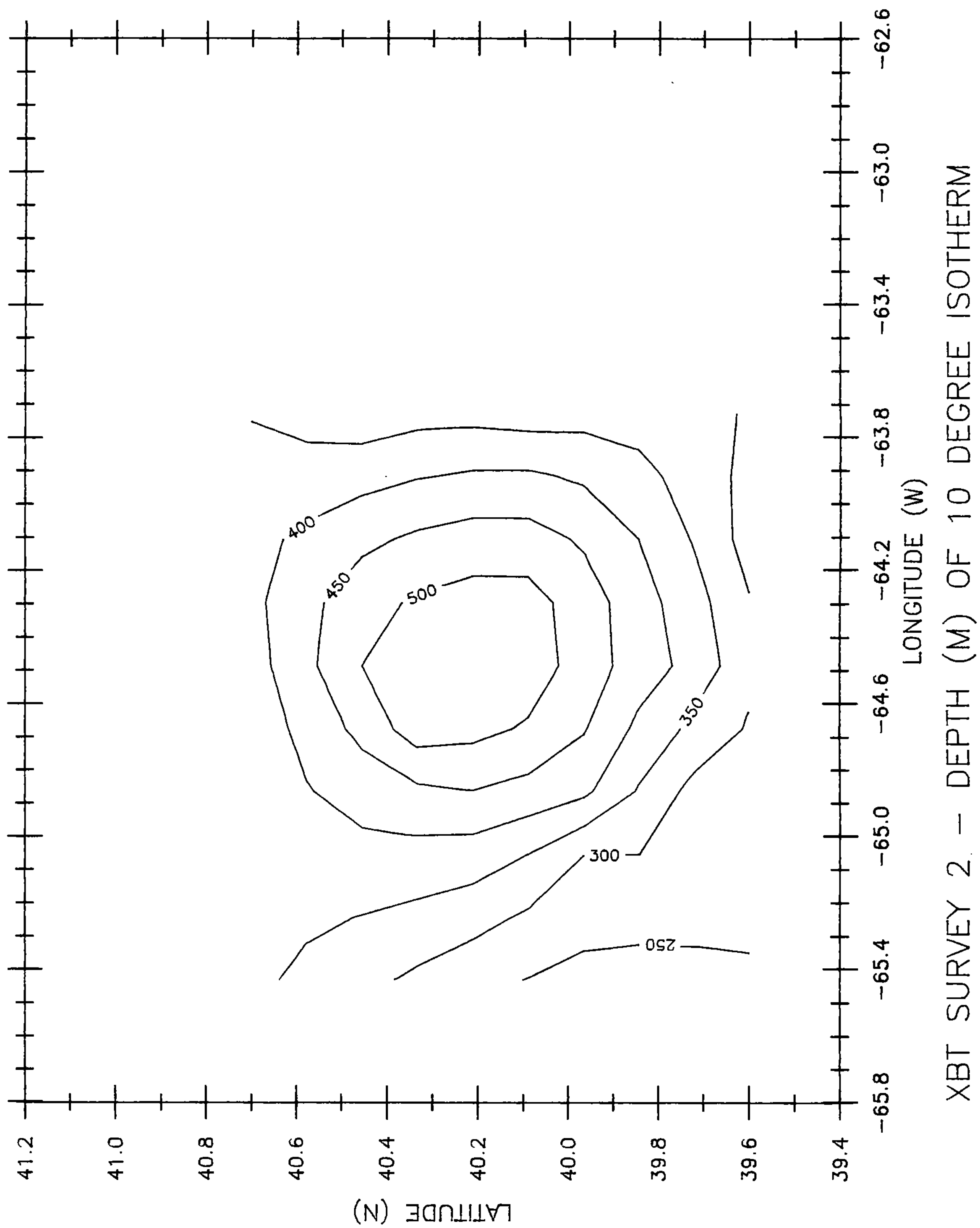

Figure 16: Depth of the 10° isotherm during XBT Survey 2 .

Summary

Oceanus 218 was a very successful cruise. A strong warm core ring was located and surveyed. In terms of operations, nearly all the expendables worked well and the free instruments were deployed and retrieved successfully. Data quality appears to be quite high. Scientifically, the hypothesis of strong mixing in association with near-inertial waves trapped in the warm ring is clearly confirmed. Future data analysis will attempt to quantify the rates of mixing and implications for wave decay within the rings.

Processed data from the XBT, XCP, CTD and HRP profiles obtained during Oceanus 218 will be provided to the Canadian Government and the National Oceanographic Data Center by April 1, 1992.

Acknowledgments

The ship handling skills of the crew of Oceanus were an important factor in the success of the cruise. The WHOI Port Office (especially Barbara Martineau) and Shipboard Services Support Group were very helpful in cruise preparations. We also thank Veta Green for her efforts in preparing this report. The support of the Ocean Sciences Division of the National Science Foundation (Grant OCE 89-11053) is gratefully acknowledged.

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16. Abstract (Limit: 200 words)

R/V Oceanus Cruise 218 (OC218) departed Woods Hole March 20, 1990 for 20 days of work in a Gulf Stream Warm Core Ring. The scientific objective of the Warm Ring Inertial Critical Layer Experiment (WRINCLE) was to study the phenomenon of inertial-internal wave trapping in anticyclonic rings and the associated mixing. High Resolution Profiler (HRP) casts provided fine- and microstructure data, and the Richardson Number float and eXpendable Current Profiler (XCP) surveys provided velocity and density finestructure measurements.

During the time R/V Oceanus was in and around the ring, 78 HRP drops to 1000 m were completed, and data from 55 XCPs, 26 Conductivity Temperature and Depth Profiler (CTD) casts, and 59 eXpendable BathyThermograph (XBTs) were logged. The free-drifting Richardson Number float (RiNo) acquired data for eleven days in ring center.

This report documents the work performed at sea, and summarizes some of the data collected.

17. Document Analysis a. Descriptors

1. vertical structure and mixing
2. warm core ring
3. fine- and micro- structure

b. Identifiers/Open-Ended Terms

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